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The Proper Identification of the Heavy Baryons

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Abstract

The new designation of heavy baryons proposed by Falk is shown to violate minimal symmetry sum rules.

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A new interpretation has been proposed by Falk[1] for the heavy baryons because the conventional assignments violate mass relations that Falk bases on heavy quark effective theory and SU(3) symmetry. However, we show here that Falk's proposed new baryon designations violate more general mass sum rules[2, 3] that are based on a smaller set of assumptions than those used by Falk. The more general sum rules are satisfied by the conventional baryon assignments.

Three of these sum rules that can be tested with the present set of observed heavy baryons are

$$(\Sigma^{*0}-\Lambda^0)+\frac{1}{2}(\Sigma^0-\Lambda^0) = (\Sigma_c^{*+}-\Lambda_c^+)+\frac{1}{2}(\Sigma_c^+-\Lambda_c^+) \tag{1}$$

$$(307^{+23}_{-10}) \qquad\qquad (330\pm 7)$$

$$= (\Sigma_b^{*0}-\Lambda_b^0)+\frac{1}{2}(\Sigma_b^0-\Lambda_b^0). \tag{2}$$

$$(316\pm 10)$$

$$\Sigma^+ + \Omega^- - \Xi^0 - \Xi^{*0} = \Sigma_c^{++} + \Omega_c^0 - 2\Xi_c'^{+}. \tag{3}$$

$$(15^{+12}_{-18}) \qquad\qquad (27\pm 30)$$

The experimental value in MeV of each baryon sum is given below each equation, using the heavy baryon masses given in Ref.[1] with the conventional assignments. The $\pm$ values for the light baryons result from the fact that three different light baryon combinations could be used in each equation.[3]

These sum rules require no symmetry assumptions about interactions or wave functions. They are based on two assumptions:

1. The ground state baryons are composed of three spin one-half colored quarks whose spins add up to the baryon spin with no orbital angular momentum.

2. The interaction energy of each pair of quarks does not depend on the third quark in the baryon.

Both of these assumptions are used (at least, implicitly) in deriving Eqs. (1)-(7) of Ref.[1]. A number of additional assumptions are also made in deriving some of the seven equations in Ref.[1]. Note, however, that the equality between the c- and b-baryon combinations in our Eqs. (1) and (2) is the same as Eq. (2) in Ref.[1]. That relation does not depend on any heavy baryon assumption, and we see no reason to separate it from the light baryon sector.

Based on the failure of two of the relations in Ref.[1], Falk has proposed alternate assignments for the Σ_c^*, Σ_c, Σ_b^*, and Σ_b baryons. He proposes that the heavy baryons that have been considered as the Σ baryons, in fact are the Σ^* baryons. The actual heavy Σ baryons would then be lower in mass, and not as yet detected. However if the $\Sigma_c^*(2530)$ baryon in Eq. (1) above is replaced by the $\Sigma_c(2453)$, and the Σ_c by a lower mass baryon, then the right hand side decreases by at least 77 MeV to become < 253 MeV. Our sum rule (1) is then no longer in reasonable agreement. Putting in Falk's proposed $\Sigma_c(2380)$ further lowers the right hand side of Eq. (1) to 216 MeV, worsening the disagreement. Replacing the $\Sigma_b^*(5852)$ by $\Sigma_b(5796)$ would change the right hand side of Eq. (2) to <260 MeV, and using a new $\Sigma_b(5760)$ would make it 224 MeV, so that the b-baryon sum rule would no longer agree. Using the proposed $\Sigma_c(2380)$ in Eq. (3) changes the right hand side to -46$\pm$30 also putting it into disagreement.

We see that Falk's proposed heavy baryon assignments violate all three of the sum rules above, while the sum rules are satisfied by the conventional heavy baryons.

The two relations that do not agree with the standard heavy baryon designations are equations (3) and (7) of Ref.[1], which are

$$\frac{\Sigma_b^* - \Sigma_b}{\Sigma_c^* - \Sigma_c} \quad = \quad \frac{B^* - B}{D^* - D} \tag{4}$$

$$(0.73 \pm .16) \qquad\qquad (0.33)$$

and

$$(\Sigma_c^{*+} - \Lambda_c^+) + \frac{1}{2}(\Sigma_c^+ - \Lambda_c^+) = (\Xi_c^{*+} - \Xi_c^+) + \frac{1}{2}(\Xi_c'^{+} - \Xi_c^+). \tag{5}$$

$$(330 \pm 7) \qquad\qquad\qquad\qquad (223 \pm 9)$$

Equation (4) relies on assumptions (1) and (2) above, and also assumes that the spin-spin interaction between pairs of quarks is inversely proportional to the product of the quark masses, but otherwise independent of quark flavor and baryon location. The right hand side of Eq. (4) is equal to m_c/m_b, the ratio of c-quark to b-quark mass, as measured by the heavy meson mass combinations.

Equation (4) can be extended to the light baryons because it does not use any assumption specific to heavy baryons. That is, we can write

$$(\Delta^+ - p) : (\Sigma^{*+} - \Sigma^+) : (\Sigma_c^{*++} - \Sigma_c^{++}) : (\Sigma_b^{*+} - \Sigma_b^+) = \frac{1}{d} \;:\; \frac{1}{s} \;:\; \frac{1}{c} \;:\; \frac{1}{b} \tag{6}$$

$$(297) \quad : \quad (194) \quad : \quad (77 \pm 7) \quad : \quad (56 \pm 11) = (297):(192)(61):(20)$$

where we have used the quark symbol for its mass. The numbers under the right hand side of Eq. (6) have been normalized to the Δ^+-p mass difference in MeV, using the quark masses

$$u = d = 330 MeV, \quad s = 510 MeV, \quad c = 1.6 GeV, \quad b = 4.8 GeV. \tag{7}$$

Looking at Eq. (6) we see that the $\Sigma_c^* - \Sigma_c$ mass difference is not unreasonable with the conventional assignments, but the $\Sigma_b^* - \Sigma_b$ difference is too large. However there are a number of three body effects that can be expected to modify Eq. (6).[5] In fact, it is generally true that relations involving spin $\frac{3}{2}$-spin $\frac{1}{2}$ mass differences are only accurate to about 20 MeV. This is seen in light baryon mass splittings[3, 4], and in heavy baryon mass splittings, as in Ref.[3] and Eqs.(2), (4), and (6) of Ref.[1] Taking this into account makes the b-baryon mass difference look not quite as serious a problem as when a small number is put into a ratio, as in Eq.(4), magnifying the effect of the 36 ± 11 MeV difference between the two sides of Eq. (6) for $\Sigma_b^* - \Sigma_b$.

Falk describes Eqs. (4)-(7) of Ref.[1] as including corrections linear in the strange quark mass. However, in equation (5) [equation (7) of Ref.[1]], which agrees badly with the conventional heavy baryon assignments, the mass splitting of the left hand side is proportional to 1/ud, while the right side mass splitting is proportional to 1/ds. This results in a relatively large difference in the two sides of Eq. (5), proportional to the quark mass ratio (s-u)/uds which persists even in the heavy quark limit. In fact, since the baryon combinations in Eq. (5) were chosen to cancel out the heavy quark spin contribution, they do not rely on any heavy quark assumptions and should apply equally well (or badly) to the light baryon sector. If exactly the same assumptions that went into Eq. (5) above were applied to the light baryons, then the relation

$$(\Sigma^{*0} - \Lambda) + \frac{1}{2}(\Sigma^0 - \Lambda) = \Xi^{*0} - \Xi^0 \tag{8}$$

$$(307) \qquad\qquad\qquad\qquad (217)$$

could be written. Equation (8) has just the same disagreement as Eq. (5). We conclude that the spin-spin correction term proportional to (s-u)/usd cannot be safely ignored in either the light or heavy baryon sector.

Our conclusion is that there is no good reason to change the conventional designation of heavy baryons, and strong evidence in Eqs. (1)-(3) against the heavy baryon assignents proposed in Ref. 1.

References

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[5] The possible importance of three body effects has been emphasized by D. B. Lichtenberg, Indiana University preprint IUHET-332, hep-ph/9606340.